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Development of Lithium Diffused Radiation Resistant Solar Cells

Report No. 9

Third Quarterly Report

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15 April 1970

JPL Contract No. JPL 952547

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, as sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

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SUMMARY

During this quarter TiPdAg and Al contact systems on P/N cells were evaluated for strength and humidity resistance. The results are presented and comparison is made to TiAg contacts on P/N cells.

Investigation of lithium evaporation led to a process which duplicates the lithium concentration and concentration profiles obtained with the painted-on lithium mineral oil suspension. Data comparing cell output as a function of method of lithium application is presented.

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1.0 INTRODUCTION

The goal of this contract is to investigate the effect of various process parameters on lithium doped solar cell performance. This program is a continuation of work done on JPL contract 952247, and it has been organized into five areas of study. The five basic areas include: P-N diffusion studies, material studies, lithium diffusion studies, special structure studies and contact studies.

The purpose of the P-N diffusion studies is to develop a boron diffusion which: 1) does not etch silicon, 2) will yield higher efficiency lithium cells due to reduced stresses and 3) can be used for larger area and thinner cells (also due to reduced stresses).

As part of the material studies parameters such as oxygen content, crystal growth rate and blank thickness will be investigated.

The lithium diffusion studies will be directed toward improving cell efficiency and obtaining maximum radiation damage recovery. Radiation studies conducted under JPL contract by other laboratories during the past year have shown in one limited experiment that long lithium diffusions done around 325°C result in higher efficiency and more radiation resistant lithium cells. These diffusion parameters as well as the process techniques of complete lithium coverage of the back cell surface and lithium evaporations were used in fabricating the cells that showed unusually good radiation recovery, so these same parameters will be further investigated in this program in order to determine if these results can be reproduced.

The contact studies will include evaluation of the TiAg contacts presently used as well as investigation of other contact metals such as Pd and Aℓ.

The special structures to be studied will be lithium cells with integral covers and a lithium cell with a high concentration N+ region at the junction.

In addition to the experimental studies, 600 lithium doped solar cells will be fabricated for radiation testing and analysis by JPL.

During this quarter TiPdAg and Aℓ contacts on P/N cells were evaluated for strength and humidity resistance. Lithium evaporation as an alternative to painting on a lithium mineral oil suspension was investigated. The I-V characteristic curves and concentration profiles obtained with the two methods of lithium application were compared.

2.0 TECHNICAL DISCUSSION

2.1 CONTACT EVALUATION

During this contract the TiAg contacts on lithium cells were evaluated with respect to humidity resistance and strength. Their performance was summarized in the previous quarterly report. During this quarter the same evaluation was performed on P/N cells with Aℓ and TiPdAg contact systems.

The cells were subjected to 95% relative humidity at 65°C and periodically I-V curves were measured and tape peel tests were performed. Aℓ and TiPdAg contacts exhibit more humidity resistance than TiAg contacts. Whereas significant peeling (35%) of the TiAg grid lines occurred after approximately 100 hours exposure, no mechanical degradation as measured by the tape peel test occurred with the TiPdAg and Aℓ contacts until after 244 hours. When tape tested after 244 hours no peeling occurred. However, after 288 hours 2 out of 10 of the Aℓ contacted lithium cells exhibited peeling: 30% of the bar on one cell and 80% of the bar on another cell. One out of ten of the TiPdAg contacted lithium cells had about 20% of the bar peel. In addition to the lithium cells, P/N cells with TiPdAg contacts and no lithium were also subjected to this humidity test. Approximately 2% of the back contact of one of the cells peeled after 92 hours and 1-2% more peeling occurred after 288 hours. Another cell from this group of ten had a small blister lift but not peel after 288 hours. The behavior of these contacts is superior to the unsoldered TiAg which had peeled significantly after 100 hours and 100% (front contact) after 200 hours.

I-V curves were measured and the I_{sc}, I at 450 mV, and V_{oc} for each cell after each time increment is shown in Table I. The P/N cells with TiPdAg contacts which had no lithium generally showed less than 1% degradation. The I at 450 mV of cell #7738 degraded 1.08% and the

TABLE I.

RESULTS OF HUMIDITY TESTING OF P/N CELLS

Cell No.	Test	ELECTRICAL CHARACTERISTICS Time at 65°C and 95% Relative Humidity Initial	92 hrs.	134 hrs.	177 hrs.	244 hrs.	288 hrs.
Li Cells							
6592	I_{sc}	48.0	48.1	47.5	47.8	47.3	47.1
Aℓ	I at 450	44.0	44.0	43.0	42.5	43.0	41.0
	V_{oc}	552	550	549	549	549	547
6593	I_{sc}	54.5		54.1	54.2	53.9	54.1
Aℓ	I at 450	51.0		49.8	50.0	50.0	50.0
	V_{oc}	565		558	562	562	560
6595	I_{sc}	51.5	51.7	50.8	-	-	-
Aℓ	I at 450	47.8	47.5	47.3	-	-	-
	V_{oc}	563	562	561	-	-	-
6599	I_{sc}	53.9	54.1	53.2	53.6	53.1	53.3
Aℓ	I at 450	50.6	49.2	48.3	47.3	48.4	37.7
	V_{oc}	566	562	563	565	564	562
6600	I_{sc}	51.5	51.7	50.9	51.0	50.7	50.8
Aℓ	I at 450	47.5	47.7		47.0	46.0	35.2
	V_{oc}	559	557		557	556	553
6601	I_{sc}	51.5	48.3	47.5	47.8	-	47.8
Aℓ	I at 450	47.7	41.0	42.0	42.3	-	29.0
	V_{oc}	558	547	546	548	-	547
6602	I_{sc}	53.9	54.3	53.7	53.7	53.1	53.3
Aℓ	I at 450	49.7	48.7	48.9	49.0	48.7	48.7
	V_{oc}	566	565	564	562	562	558
6603	I_{sc}	51.4	51.7	50.7	50.8	50.4	50.5
Aℓ	I at 450	48.6	47.5	47.1	47.6	47.2	47.2
	V_{oc}	563	562	557	561	558	558
6604	I_{sc}	50.5	50.8	50.0	50.2	49.9	50.0
Aℓ	I at 450	47.7	47.7	46.7	47.6	-	45.7
	V_{oc}	566	564	564	566	562	559
6605	I_{sc}	56.7	56.7	56.3	56.3	56.0	56.3
Aℓ	I at 450	54.1	54.0	53.0	53.8	53.0	53.1
	V_{oc}	581	581	576	580	575	574

(cont)

ELECTRICAL CHARACTERISTICS

Cell No.	Test	Initial	Time at 65°C and 95% Relative Humidity 92 hrs.	134 hrs.	177 hrs.	244 hrs.	288 hrs.
7750	I_{sc}	47.5		46.9	47.0	46.5	46.8
TiPdAg I at 450		42.5		41.6	42.0	41.9	41.6
	V_{oc}	541		542	542	542	542
7751	I_{sc}	42.0		41.4	41.6	41.2	41.3
TiPdAg I at 450		37.5		36.5	37.0	37.0	36.4
	V_{oc}	535		531	530	533	532
7752	I_{sc}	44.6		43.8	44.3	44.0	44.1
TiPdAg I at 450		39.9		38.5	39.1	38.9	38.6
	V_{oc}	535		535	535	535	532
7753	I_{sc}	44.6		43.9	44.0	43.5	43.5
TiPdAg I at 450		40.0		39.1	39.7	39.0	39.1
	V_{oc}	543		541	542	541	536
7754	I_{sc}	44.5		43.5	43.9	43.5	43.6
TiPdAg I at 450		34.0		33.4	34.0	33.5	33.3
	V_{oc}	523		522	525	524	521
7755	I_{sc}	41.8		41.0	41.0	41.0	40.8
TiPdAg I at 450		34.5		34.2	34.5	34.5	34.2
	V_{oc}	525		523	525	525	523
7756	I_{sc}	55.0		54.9	54.8	54.9	54.9
TiPdAg I at 450		47.0		46.4	47.0	46.5	46.6
	V_{oc}	550		551	550	550	548
7757	I_{sc}	53.4		53.0	53.0	52.3	52.2
TiPdAg I at 450		47.0		46.0	46.5	46.6	46.2
	V_{oc}	547		543	546	547	544
7760	I_{sc}	59.5		59.4	59.5	59.8	60.1
TiPdAg I at 450		46.0		45.7	46.0	46.1	46.0
	V_{oc}	543		542	543	544	542
7763	I_{sc}	57.7		57.0	57.7	57.4	57.9
TiPdAg I at 450		44.3		44.2	44.3	44.2	44.1
	V_{oc}	536		540	538	538	538
Cells with no Lithium							
7736	I_{sc}	61.0		61.2	61.0	61.0	-
	I at 450	55.5		55.3	55.0	54.4	-
	V_{oc}	556		556	555	555	-

(Cont)

ELECTRICAL CHARACTERISTICS

Cell No.	Test	Initial	Time at 65°C and 95% Relative Humidity 92 hrs.	134 hrs.	177 hrs.	244 hrs.	288 hrs.
7737	I_{sc}	60.9		61.0	60.9	60.9	61.2
	I at 450	54.9		54.0	54.3	54.3	54.2
	V_{oc}	550		549	551	551	549
7738	I_{sc}	61.6		61.6	61.0	61.0	61.5
	I at 450	55.3		54.0	54.7	54.7	54.7
	V_{oc}	554		546	554	554	552
7739	I_{sc}	58.0		58.0	58.0	57.9	58.1
	I at 450	51.5		51.4	51.6	51.8	51.8
	V_{oc}	547		546	549	549	548
7740	I_{sc}	57.0		56.5	56.6	56.5	56.8
	I at 450	45.6		45.4	45.5	45.6	45.2
	V_{oc}	533		531	534	535	532
7741	I_{sc}	62.5		62.5	62.5	62.1	62.6
	I at 450	55.2		54.5	55.5	55.7	55.9
	V_{oc}	555		550	555	556	555
7742	I_{sc}	51.0		50.4	50.6	50.3	50.7
	I at 450	41.5		41.0	41.0	41.5	41.3
	V_{oc}	525		526	526	526	526
7743	I_{sc}	60.0		60.0	60.1	60.1	60.4
	I at 450	53.5		53.5	53.8	53.6	53.9
	V_{oc}	549		550	551	551	550
7744	I_{sc}	62.0		61.4	61.5	61.1	61.7
	I at 450	55.3		55.5	55.3	55.4	55.3
	V_{oc}	553		554	556	555	554
7745	I_{sc}	59.6		59.7	broken		
	I at 450	52.6		51.5			
	V_{oc}	546		541			

I_{sc} of cell #7744 degraded 1.45% after 288 hours. The degradation of lithium cells with TiPdAg contacts after 288 hours ranged from 0-3.3% for the I at 450 mV, from 0-2.5% for the I_{sc}, and less than 1% for the V_{oc}. In the case of the lithium cells with Aℓ contacts the degradation for 8 out of 9 of the cells after 244 hours was similar to that of the TiPdAg contacted lithium cells after 288 hours. After 288 hours 3 out of 9 of the Aℓ contacted lithium cells exhibited high series resistance. Figure 1 shows one of these cells.

The strength of the TiPdAg contacts was tested by soldering a wire to the cell and pulling at a 90° angle. Pull strengths of greater than 500 grams were obtained. The Aℓ contact strength was tested by ultrasonically welding a tab to the cell. The area of this bond is approximately one-eight the area of a typical soldered bond and therefore the peel strengths are lower. The peel strengths ranged from 180 to 270 grams. Comparison of soldered and ultrasonic bonds on TiAg contacts have shown that 180 to 270 grams for an ultrasonic bond is comparable to more than 500 grams for a soldered bond. These tests indicate that both TiPdAg and Aℓ contacts have strengths comparable to TiAg contacts.

2.2 LITHIUM EVAPORATION

The lithium evaporation as an alternative to painting on a lithium mineral oil suspension was investigated during this quarter. Application of the lithium by evaporation is desirable for several reasons: 1) it is less tedious than the paint-on technique, 2) it is adaptable to a production line, and 3) there is no problem with the uniformity of the layer on different parts of the same cell and from cell to cell.

Larger diameter (0.125") lithium wire was used as the source. This was handled far more easily than the lithium pellets which have previously been used in investigations of lithium evaporation. Oxidation of lithium while opening the vacuum system was another problem area which

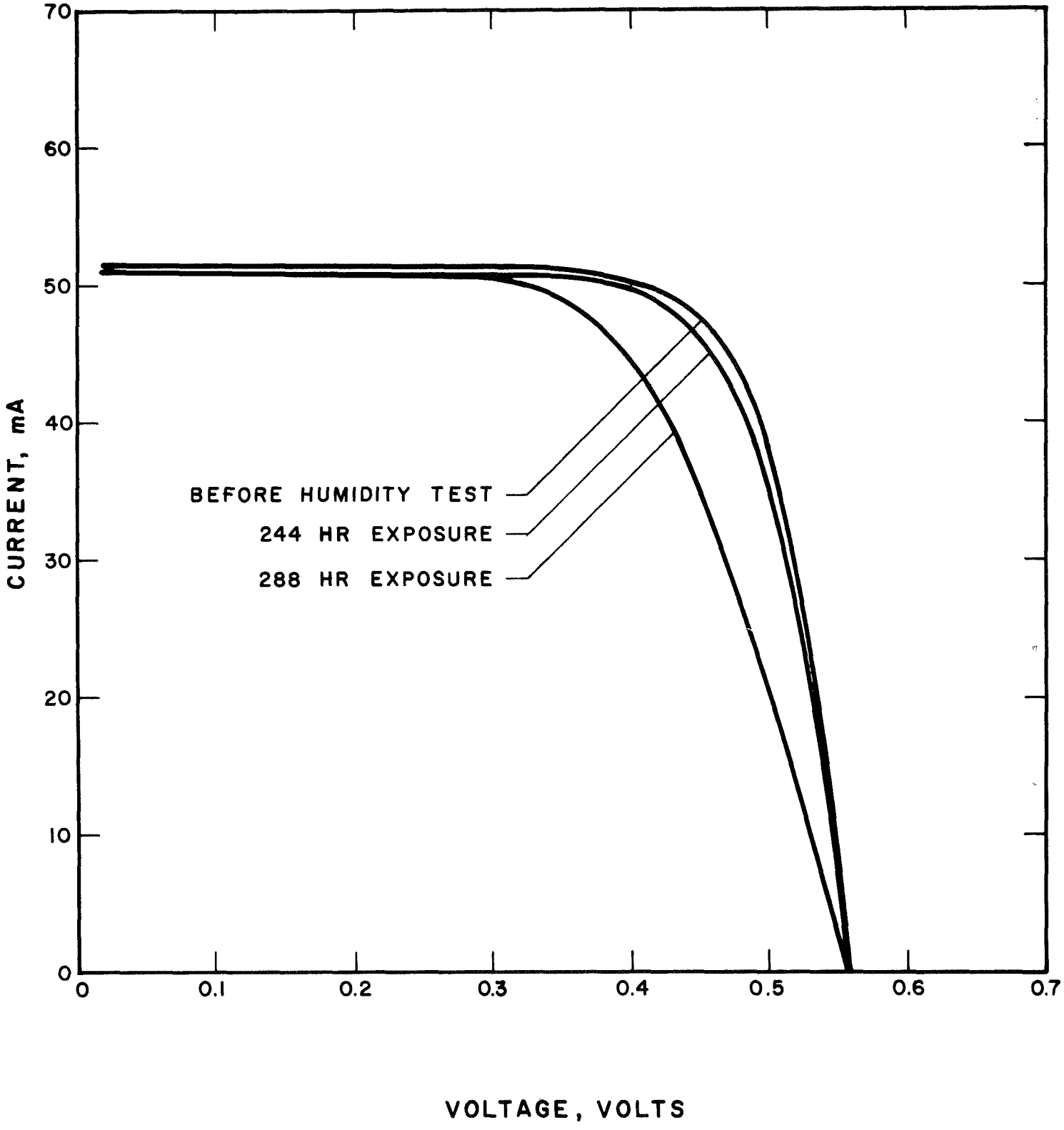

Figure 1. Effect of Humidity on Aluminum Contacted P/N Cells. 95% Relative Humidity at 65°C; cell measured in 100 mW/cm^2 Tungsten Light source.

had been encountered previously. This problem has been reduced by using helium rather than air to open the vacuum system after the lithium evaporation. The cells have been exposed to air during transfer from the vacuum system to the diffusion furnace, but with apparently little oxidation since cells have been obtained with the same V/I's and lithium concentration profiles as cells with the painted-on lithium mineral oil source. Many of the cells with evaporated lithium have outputs as high as cells with painted-on lithium; however, comparison of the cumulative frequency distributions for cells with painted-on vs evaporated lithium layers, showed that there was more fall-off in cell output and, therefore, a larger percentage of lower output cells with the evaporated lithium. Figure 2 shows the maximum power distributions as a function of lithium application technique for lots 3 and 4. At a cumulative frequency of 90%, there is a difference in output of about 1 mW for both lots.

2.3 CELLS FOR SHIPMENT

The fourth and fifth shipments of 60 experimental cells each were delivered to JPL during this quarter. Lot 4 consisted of 60 cells fabricated from 20 ohm cm float zone silicon. The cells were diffused eight hours at 325°C. The maximum power distribution for this group of 108 cells is shown in Figure 3. The average output was 24.2 mW, 5% of the cells were above 27.6 mW and 95% were above 21.5 mW. These same lithium diffusion parameters have previously been used on crucible grown cells and the outputs were significantly higher (see Figure 4). The average output of the crucible grown lithium cells was 6 mW higher than the average output of the float zone cells. In terms of efficiency this corresponded to an average efficiency of 9% for the float zone cells and 11% for the crucible grown lithium cells. It is typical for crucible grown lithium cells to have higher outputs than float zone lithium cells but usually the difference is 2-3 mW or half an efficiency group. In order to determine whether the low output was a boron diffusion, lithium diffusion, or material problem, more investigation will be necessary.

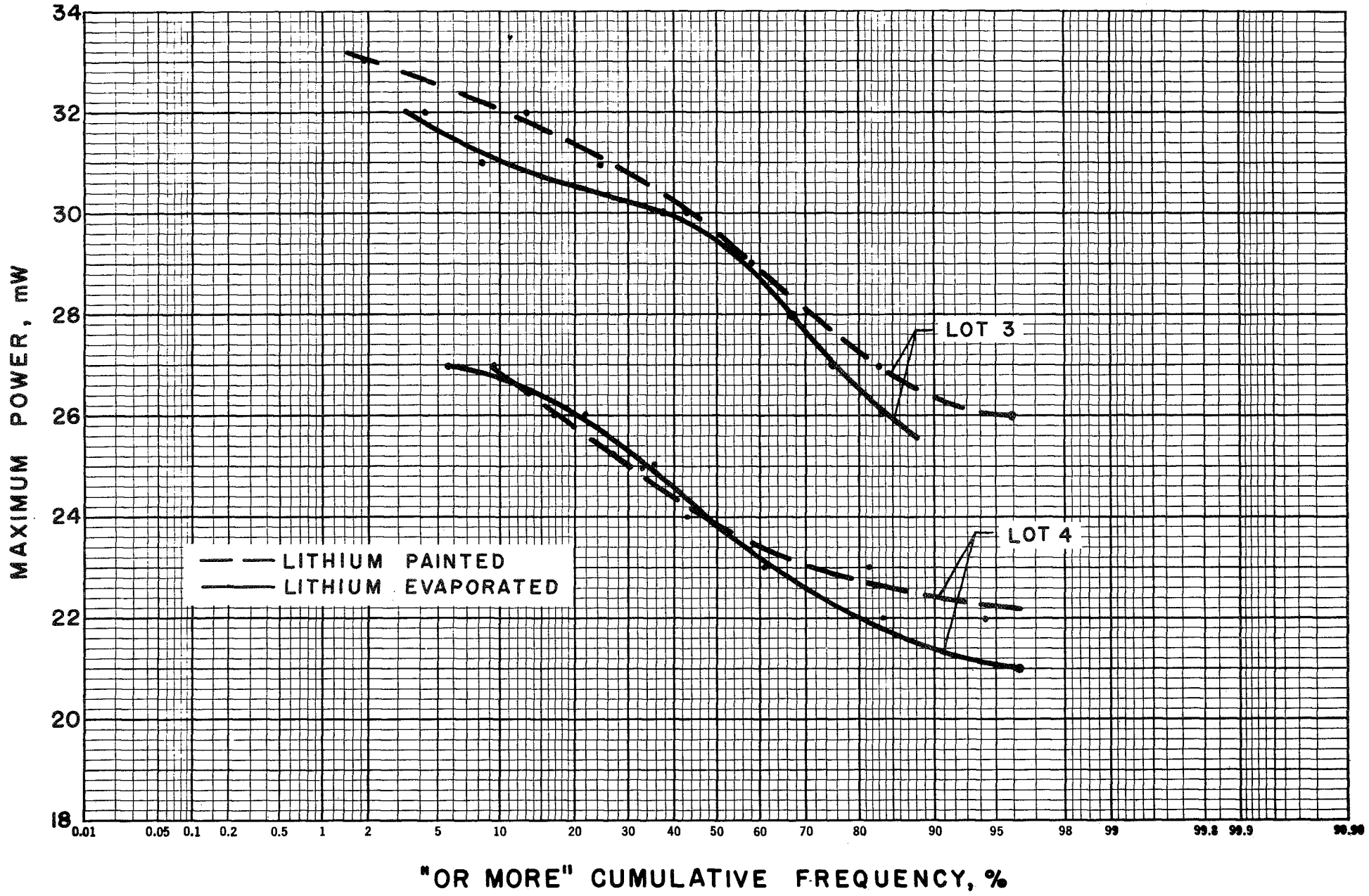

Figure 2. Maximum Power Distributions of Lithium Cells. Measured in solar simulator at 140 mW/cm^2.

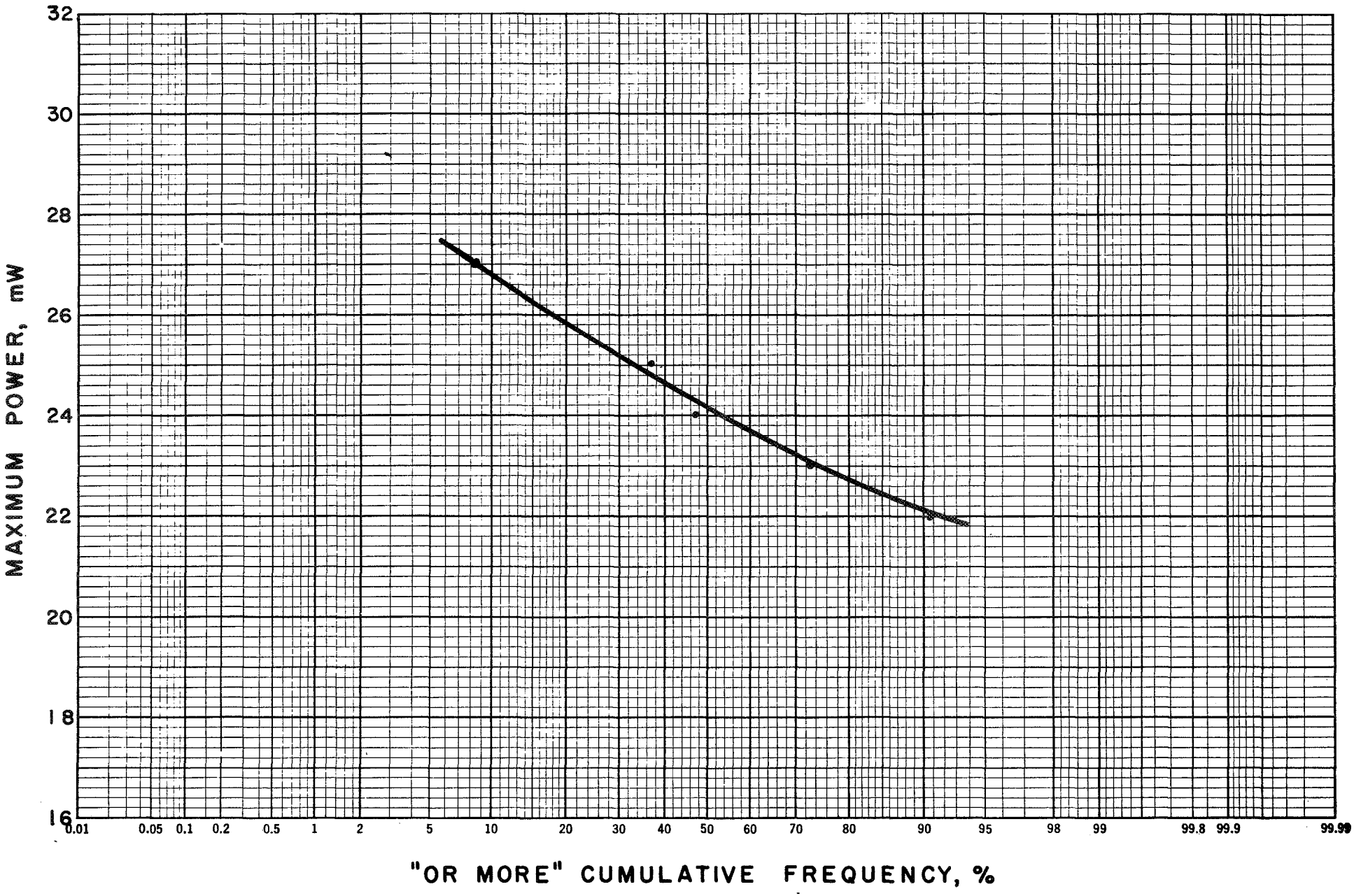

Figure 3. Maximum Power Distribution of Lithium Cells Fabricated for the Fourth Lot (108 Cells). 20 ohm cm float zone cells, lithium diffused 8 hours at 325°C; measured in solar simulator at 140 mW/cm^2.

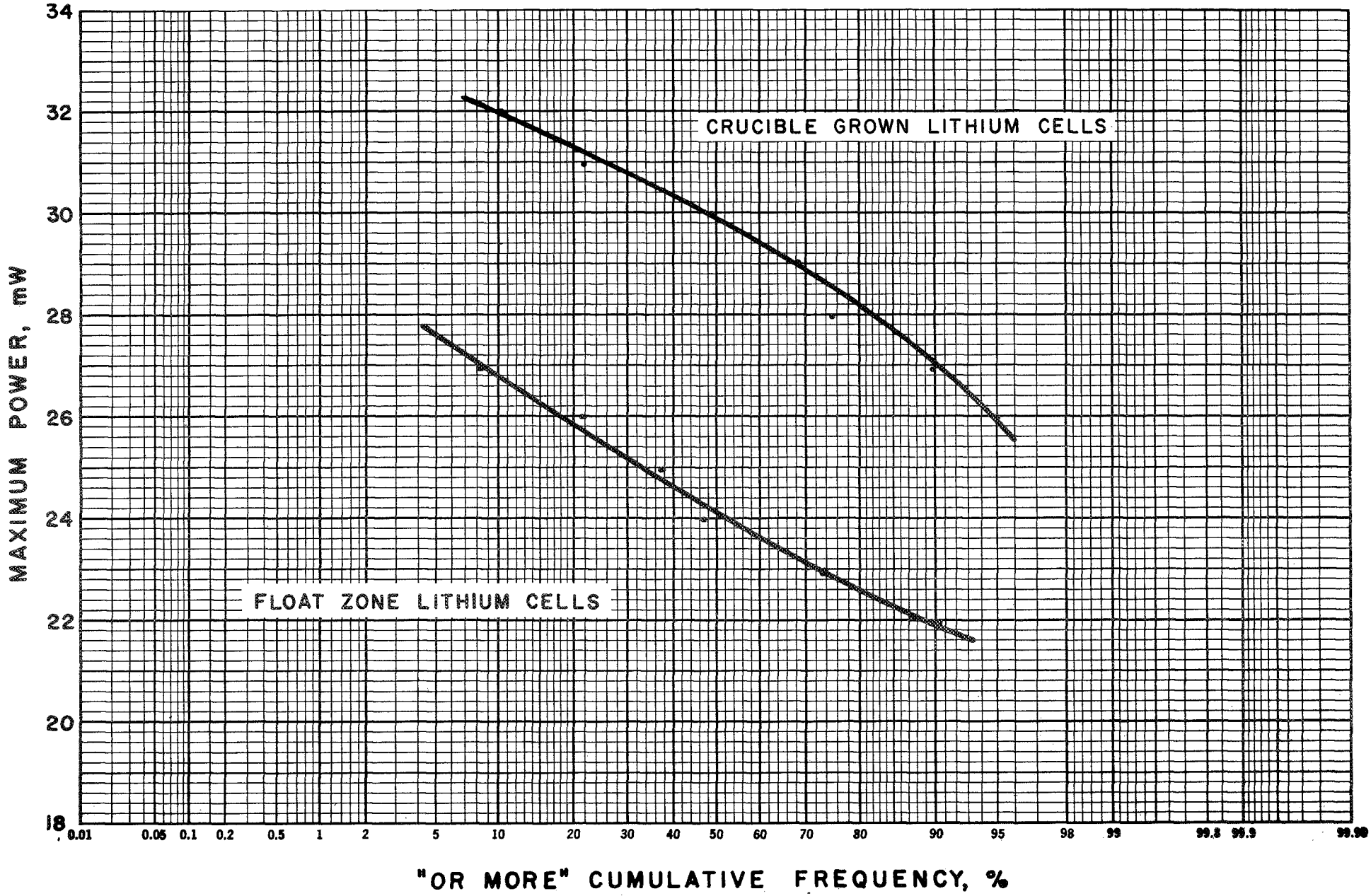

Figure 4. Comparison of Float Zone and Crucible Grown Lithium Cells Diffused 8 Hours at 325°C. Measured in solar simulator at 140 mW/cm^2.

Lot 5 consisted of thirty float zone cells lithium diffused 60 minutes and redistributed 120 minutes at 425°C plus thirty experimental cells fabricated to determine the radiation recovery characteristics as a function of lithium coverage. Three variations in lithium coverage were used: for the first group the entire back surface was covered with lithium, the second group had approximately 80% of the surface covered with lithium, and the third group had only 50% of the surface covered with lithium. These cells should provide information which indicates whether or not it is important to completely cover the back surface of the cell with lithium in order to obtain complete recovery after irradiation.

The maximum power distribution for the other thirty cells is shown in Figure 5. The thirty cells were selected from a group of fifty-eight, and all fifty-eight were used for the distribution. The average output was 25.5 mW, 5% of the cells had outputs ≥27.0 mW and 95% had outputs ≥23.6 mW.

3.0 CONCLUSIONS

TiPdAg and Aℓ contact systems have been applied to lithium cells and evaluated for humidity resistance and strength. Both contact systems withstood approximately 250 hours in a 65°C, 95% relative humidity environment with insignificant mechanical degradation and a maximum of 3% electrical degradation. After 288 hours two cells in each group showed severe mechanical and electrical degradation. Both contact systems exhibit more humidity resistance than the TiAg contact which begins to show as much as 30% mechanical degradation after 100 hours.

The strength of both the TiPdAg and Aℓ contacts is comparable to space-qualified TiAg contacts.

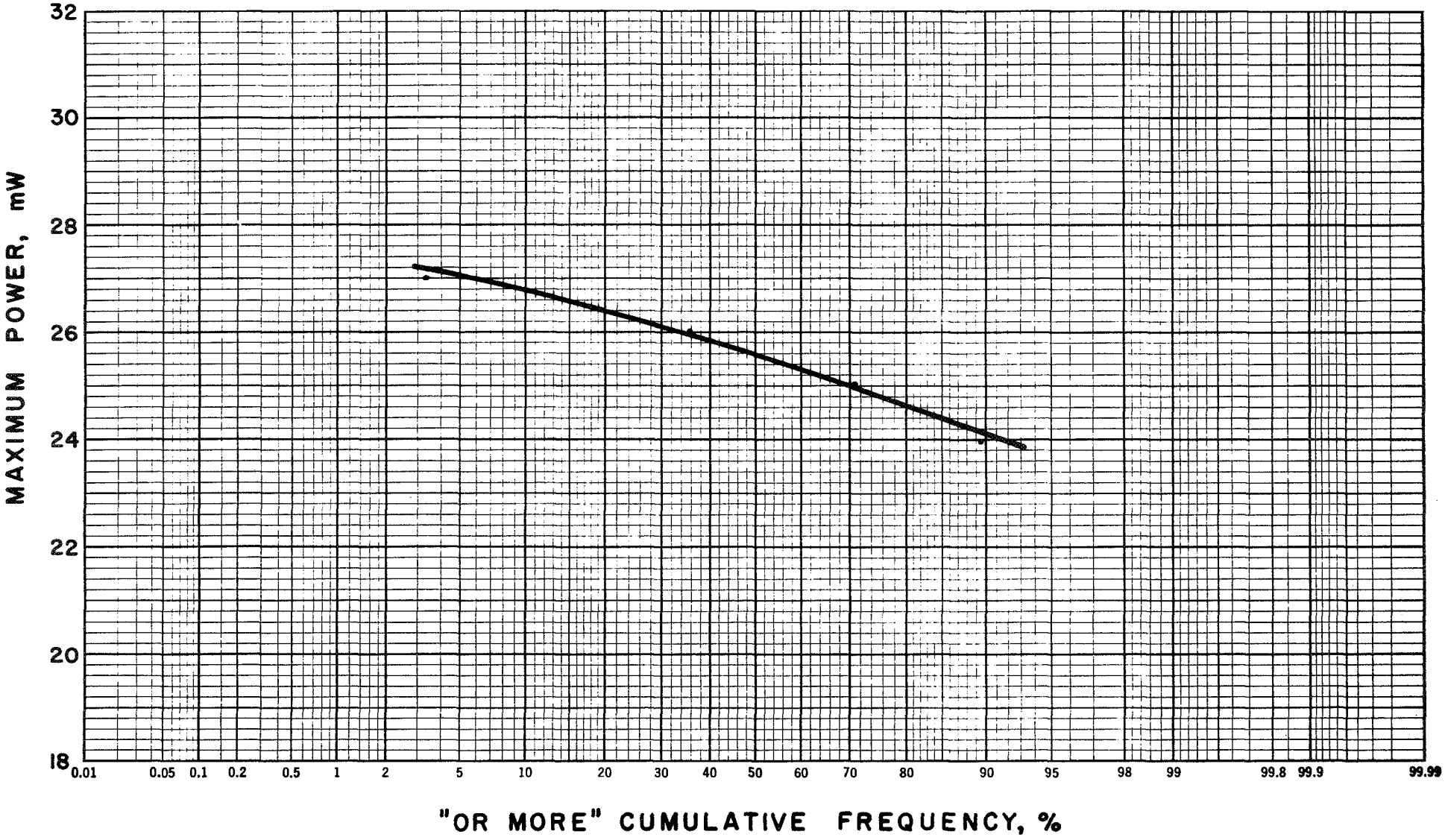

Figure 5. Maximum Power Distribution of Lithium Cells Fabricated for the Fifth Lot (58 Cells). 20 ohm cm float zone cells; lithium diffused 60 minutes and redistributed 120 minutes at 425°C; measured in solar simulator at 140 mW/cm^2.

A method for evaporating lithium has been developed which gives lithium concentrations and profiles similar to those obtained with the paint-on method. Thus all the experimentally determined lithium concentration profiles obtained from cells with painted-on lithium can also be used to describe cells with evaporated lithium as the source.